LA-UR-19-26049
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Title: Precision determination of the 235U neutron-capture cross section

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Intended for: Proposal

Issued: 2019-06-27

Precision Determination of the ^{235}U neutron-capture cross section

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DOE National Laboratory Announcement Number
LAB 19-2114

DOE/SC Program Office
Nuclear Physics
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PAMS LOI Trackiing Number
LOI-0000025903

Section I Research Area
DOE Office of Nuclear Energy

Abstract

Precision Determination of the ^{235}U neutron-capture cross section

J. L. Ullmann, *Principal Investigator*

A precise knowledge of the probability for the ^{235}U(n,γ) neutron-capture reaction is required for accurate calculations of reactivity and gamma-ray production in fissioning systems. Surprisingly, there are few measurements of neutron capture at neutron energies above 1 keV, and their uncertainties are mostly in the 10% or greater range. The uncertainties of the most precise data in this region, measured by Jandel et al [1], range from 6% near 10 keV to 10% at 100 keV. We propose to make a new determination of the capture cross section from 1 keV to roughly 100 keV (higher if possible) by extending the analysis of data taken previously using the DANCE gamma-ray detector array at the Los Alamos Neutron Scattering Center. Three weeks of data were obtained on a ^{235}U sample and the associated backgrounds using DANCE and the NEUANCE neutron detector array (for fission tagging). This data was analyzed to measure the probability of exciting isomers in ^{236}U at 687.5 and 1052 keV excitation by neutron capture [2], but cross sections were not determined. We propose to extend the analysis of this data to extract the capture cross sections. We will follow the method in ref 1 of normalizing the results to the fission reaction measured simultaneously in the same target, eliminating several sources of systematic uncertainty. The statistical uncertainty of this data set is expected to give cross-section results in the 3 to 5% uncertainty range up to several hundred keV neutron energy. We will investigate the effect of the isomers studied in [2] on the cross sections. In addition, we will analyze the gamma-ray emission spectra and compare them to model calculations to advance our knowledge of the models needed to predict neutron capture and gamma-ray emission.

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1. M. Jandel et al., Phys. Rev. Lett. 1**09**, 202506 (2012).
2. G. Rusev, Los Alamos Report LA-UR-18-29381 (unpublished).

Table of Contents

Background/Introduction

The fissile uranium isotope ^{235}U is present in nearly all nuclear power applications. Precise values of the cross section for the $^{235}U + n \rightarrow ^{236}U + \gamma$ neutron capture reaction are important for accurate modeling of reactor performance, as well as for predicting gamma-ray production. Although computational simulations of criticality using existing data libraries have produced results generally in good agreement with measurements, contradictions and uncertainties in the underlying data resulted in a coordinated effort to understand and reduce these uncertainties [1]. The need for precision data, with uncertainties 3% or less for ^{235}U capture at intermediate energies, was emphasized in this proposal call. ^{235}U capture has been included in the IAEA-OCD high-priority data list [2] since 2008, with a request for data with 8% uncertainty from 2.25 to 30 keV, and 3% uncertainty from 30 keV to 1 MeV. The available data has been tabulated by the National Nuclear Data Center [3], and evaluated by the CIELO collaboration [4] for inclusion into the ENDF/B-VIII nuclear data evaluation.

Remarkably, there are few measurements of neutron capture above 5 keV and their uncertainties are mostly in the 10% range. Measurements are difficult because of the need to separate gamma rays from capture from those from fission. The uncertainties of the most precise data in this region, measured by Jandel, et al. using the DANCE detector [5], range from 6% near 10 keV to 10% at 100 keV. Jandel binned the data in dE/E ~ 5% energy bins from 2 keV to 10 keV, and dE/E E ~ 10% for energies greater than 10 keV. A plot of the current capture data from 5 keV to 1 MeV, is shown in Figure 1. All of the data in the figure were obtained from the NNDC tabulation [3], which includes the full reference to the original data. The most recent ENDF evaluation (ENDF/B-VIII.0) is also shown. Most of the measurements were made by detecting one or more gammas following neutron capture. The measurements by Wallner et al. [6] were made using a different approach, employing broadly-peaked neutron sources and accelerator mass-spectrometry to measure the residual ^{236}U. The Wallner measurements appear to be slightly below the other measurements.

The CIELO collaboration [4] suggests that new higher resolution capture data will be needed to improve the evaluations of capture and fission cross sections up to 50 keV.

It is interesting to note that low-lying isomeric states in ^{236}U can be excited in neutron capture, most notably the 1^- level at 687.5 keV ($t_{1/2}$ = 3.78 ns) and the 4^- level at 1052.4 keV ($t_{1/2}$=100 ns). Preliminary analysis by Rusev [7] of ^{235}U capture data in the resonance region using the DANCE detector suggested 30% to 40% population of these isomers. Their excitation is clearly seen in the 2-gamma summed-energy decay spectrum observed at DANCE (see below). It is not clear how excitation of isomeric states would have affected other gamma-ray measurements which might rely on fast timing, but they would not have affected the accelerator mass spectrometry result.

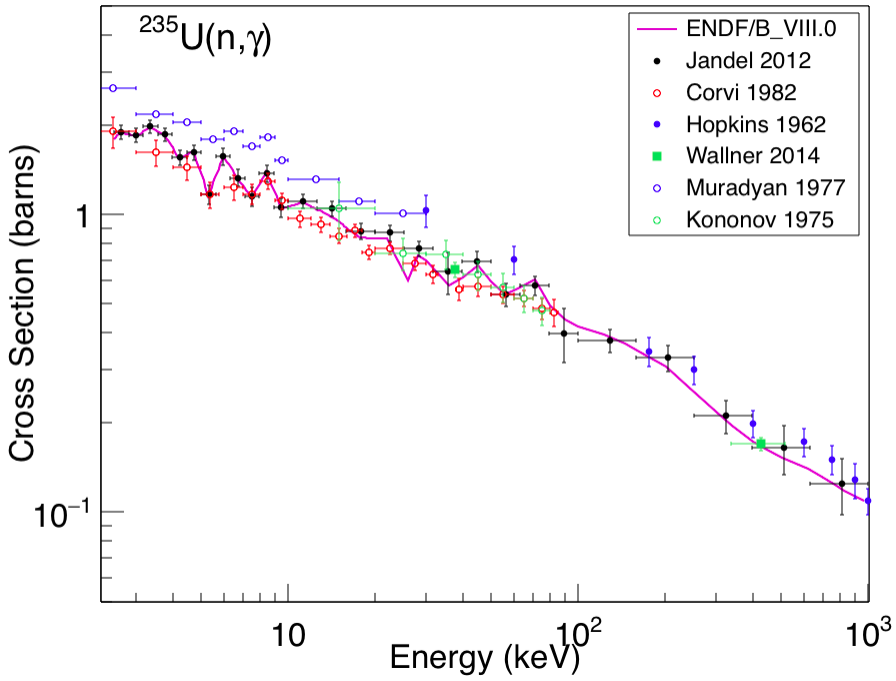

Figure 1. ^{235}U(n, γ) cross section measurements compared to ENDF/B-VIII evaluation. All data were obtained from the CSISRS/EXFOR data base [3].

Proposed Research and Methods

We propose to analyze data taken previously using the DANCE detector and the NEUANCE fission-tagging array. Three weeks of data were taken to study low-lying isomer production in the ^{235}U capture reaction, the isomer data were analyzed [7], and the project has ended. The data were not analyzed to obtain capture cross sections.

The DANCE detector (Detector for Advanced Neutron Capture Experiments) is a nearly 4π array of 160 BaF_2 crystals designed to make measurements of neutron capture on small quantities of rare or radioactive nuclides. In addition, the high photopeak efficiency of BaF_2, coupled with the high segmentation of the array, make it ideal for measuring the multiplicity and energy of the gamma-ray cascade following neutron capture. The detector is located at 20.25 m from the upper-tier room-temperature water moderator at the Manuel J. Lujan Jr. Neutron Scattering Center at the Los Alamos Neutron Science Center (LANSCE). The neutron flux is monitored by three detectors down stream of the sample location: a ^{6}Li(n,t) monitor, a ^{3}He monitor, and a ^{235}U fission chamber. The neutron flux profile consists of a thermal Maxwellian and a 1/E tail at high energies. The neutron energy is measured by time of flight. More information on DANCE can be found in ref. [8], for example.

Fission tagging is crucial since both fission and capture produce gamma rays that are detected in DANCE. Tagging detectors usually employ thin deposits of ^{235}U in order to

detect fission fragments, and the resulting low count rate is probably the reason that capture data above a few keV are scarce. Jandel [5] used a parallel-plate avalanche counter (PPAC) with a thin (130 μg/cm^2) ^{235}U sample to characterize the gamma-ray emission spectra from fission, and then a 26 mg/cm^2 ^{235}U sample, without the PPAC, to measure neutron capture. The fission gamma-ray spectrum was scaled to the capture gamma-ray spectrum and subtracted, in each neutron energy bin. An additional background contribution to the measured spectrum is due to neutrons scattered by the target and captured in the BaF_2, producing gamma rays. This background was estimated by measuring a ^{208}Pb sample. The ^{208}Pb capture cross section is very small and also has a Q-value somewhat less than the Q value for ^{235}U capture, so the capture contribution can be eliminated in analysis. The remaining neutron scattering contribution from ^{208}Pb data was also normalized and subtracted in each neutron energy bin.

The data we will analyze used the NEUANCE array to detect fission neutrons to tag fission events. NEUANCE (NEUtron detector at dANCE) is an array of 21 stilbene detectors, each 23 mm by 23 mm by 100 mm [9]. The use of fission neutrons for the fission tag allowed the use of the thick 26 mg/cm^2 sample for a simultaneous measurement of fission and capture. Three-hundred and thirty six hours of ^{235}U capture data were obtained. For a neutron energy bin dE/E = 5% at 100 keV (100 ± 2.5 keV), an estimated 4300 capture counts and 15,000 fission counts were obtained. After background corrections, this should yield a 3% statistical uncertainty. The capture cross section varies as $1/E^{1/2}$ and the neutron flux varies as 1/E, so in the 1 to 10 keV neutron range we will be able to report cross sections with a finer neutron energy resolution.

Our analysis procedure will be similar to that of Jandel [5]. We will obtain the capture to fission ratio α from simultaneously measuring both quantities on a ^{235}U target. This is detailed in eq. 1, where $\sigma_{n\gamma(f)}$ is the capture (fission) cross section, $\varepsilon_{n\gamma(f)}$ is the capture (fission) efficiency, and $N_{n\gamma(f)}$ is the number of counts in the capture (fission) channel.

$$\alpha = \frac{\sigma_{n\gamma}}{\sigma_{nf}} = \frac{\epsilon_{nf}}{\epsilon_{n\gamma}} \frac{N_{n\gamma}}{N_{nf}} \qquad (1)$$

This eliminates the need to accurately know the neutron flux and the target thickness. The capture and fission detection efficiencies must still be accurately determined. Fission events in DANCE are characterized by high gamma-ray multiplicity and high summed energy, and the fission efficiency can be obtained by comparing the neutron fission-tagged data to these events. The fission detection efficiency depends on the average number of neutrons emitted in fission. For ^{252}Cf spontaneous fission, reported in ref. 9, the average number of neutrons is 3.76 and the measured fission efficiency was 0.47. For ^{235}U(n,f), the average number of neutrons is 2.4 at thermal, and the fission detection efficiency will be approximately 0.30. The capture efficiency can be obtained in several ways, including Monte-Carlo calculations and normalization to known resonances. The accuracy of the different methods will be evaluated.

Capture cross sections will then be obtained using the well-known ^{235}U(n,f) cross section [10]. Note that the ^{235}U fission cross section is not a “standard” in this energy region, but is listed as a “reference” value.

We will also obtain the gamma-ray spectra as a function of gamma multiplicity, and study the radiative strength function and level density needed to calculate the spectra. This will extend the previous work on even mass U isotopes [11].

In addition, we will study the cross section for the excitation of the isomers at 687.5 and 1052 keV. Figure 2, from ref 7., shows the summed-energy spectrum for a crystal multiplicity of 2, subject to a 3 eV wide gate on the capture resonance at 11.67 eV. The “background” was obtained from a 3 eV gate centered at 11.25 eV. Gamma-ray energies were summed over a coincidence window of 5 ns, this will include 60% of the decays from the 688 keV isomer, but only 3% of the decays from the 1052 keV isomer. The peak at 6.545 MeV, the Q-value of the capture reaction, represents gamma cascades to the ground state, while the peak at 5.5 MeV represents cascades through the isomers.

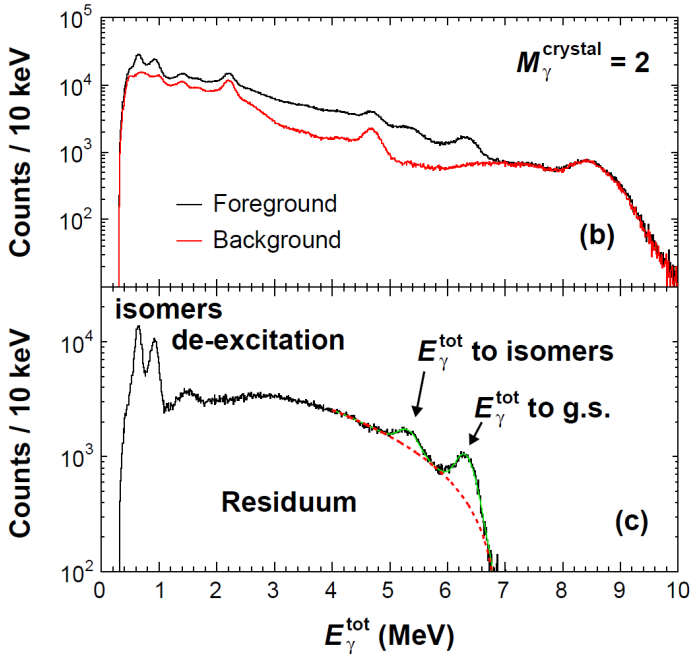

Figure 2. (Top) Summed gamma-ray energy for background and foreground events gated on the 11.67 eV resonance in ^{235}U(n,γ). See text for details. (Bottom) Difference between foreground and background. Gamma cascades to the ground state have a summed energy of 6.545 MeV. Cascades through the 1.052 MeV isomer have an energy of 5.5 MeV. (From ref. 7).

The final result will be a new measurement of the ^{235}U(n,γ) cross section, with a finer neutron energy resolution and improved uncertainties compared to previous

measurements. The isomeric ratios for the 687.5 and 1052 keV isomers will also be studied. In addition, the gamma-ray emission spectra will also be analyzed and compared to model calculations to increase our knowledge of the models needed to calculate cross sections and gamma emission.

Timetable of Activities

Data analysis will be completed in FY2020. In FY2021, the interpretation of the data will be finished and final papers prepared and presented.

Personnel Responsibilities

Ullmann will be responsible for the majority of the new analysis, with assistance from Couture. Rusev will provide calibrations, preliminary results from the isomer analysis, and assistance in understanding the contribution of the isomers. Kawano will provide theoretical cross section calculations and serve as NDP point of contact for dissemination of the results.

Project Objectives

The goal of the proposed project is to provide new cross section measurements of ^{235}U(n,γ) for neutron energies in the unresolved resonance region and the “fast” region, from 3 to 100 keV, and possibly as high as 1 MeV. The goal is to provide measurements with finer energy resolution and lower uncertainty than currently available, aiming for 3% or better statistical uncertainty. The effect of the ^{236}U isomers at 688 and 1052 keV will be included.

Appendix 1: Biographical sketches

Name and affiliation

John Ullmann
Physics Division, Group P-27
Los Alamos National Laboratory
Ullmann@lanl.gov / 505-667-2517

Education and Training

Univ. Wisconsin (Madison) BS 1968 (Physics)
Cal. Institute of. Technology. MS 1970 (Space physics)
Univ. California, Davis PhD 1981 (Nuclear Physics)
Univ. Colorado (Boulder) Post-Doc 1981 – 1985 (Nuclear Physics)

Research and Professional Experience

1986 – present	Staff Scientist, Los Alamos National Laboratory Nuclear physics research using moderated and unmoderated neutron sources, including fission cross sections, charge-exchange reactions, neutron capture, and neutron transmission. Developed the "DANCE" detector and currently instrument scientist for DANCE.
1985-1986	Assoc. Professor (Attendent Rank) University of Colorado, Boulder Nuclear physics research at TRIUMF, IUCF, and LAMPF, including work on pion elastic and inelastic scattering, and (p,n) charge-exchange reactions.
1973-1974	Research Associate, University of California, Davis Research on measuring bone mineral density.
1970-1973	Commissioned Officer, U.S. Public Health Service Measurements of bone mineral density, especially in astronauts pre- and post- space flight.

Selected Recent Publications

Isomeric ratio measurements for the radiative neutron capture ^{176}Lu(n,g) at the LANL DANCE Facility. D. Denis-Petit, O. Roig, V. Meot, B. Morillon, P. Romain, M. Jandel, T. Kawano, D.J. Vieira, E.M. Bond, T.A. Bredeweg, A.J. Couture, R.C. Haight, A.L. Keksis, R.S. Rundberg, and J.L. Ullmann; Phys. Rev. C **94**, 054612 (2016).

Measurement of the ^{242m}Am neutron-induced reaction cross section. M.Q. Buckner, C.Y. Wu, R.A. Henderson, B. Bucher, N. Wimer, A. Chyzh, T.A. Bredeweg, B. Baramsai, A. Couture, M. Jandel, S. Mosby, and J.L. Ullmann. Phys. Rev. C **95**, 024610 (2017).

Estimation of M1 scissors-mode strength for deformed nuclei in the medium to heavy mass region by statistical Hauser-Feshbach model calculations. M.R. Mumpower, T. Kawano, J.L. Ullmann, M. Krticka, and T.M. Sprouse. Phys. Rev. C **96**, 024619 (2017).

Radiative neutron capture cross section from ^{236}U. B. Baramsai, M. Jandel, T.A. Bredeweg, E.M. Bond, A.R. Roman, G. Rusev, C.L. Walker, A. Couture, S. Mosby, J. O'Donnell, J.L. Ullmann, and T. Kawano. Phys. Rev, C **96**, 024619 (2017).

the calculation of ^{234,236,238}U(n,γ) cross sections with measurements of the Gamma-ray spectra at the DANCE facility. J.L. Ullmann, T. Kawano, B. Baramsai, T.A. Bredeweg, A. Couture, R.C. Haight, M. Jandel,

J.M. O'Donnell, R.S. Rundberg, D.J. Vieira, J.B. Wilhelmy, M. Krticka, J.A. Becker, A. Chyzh, C.Y. Wu, and G.E. Mitchell. Phys. Rev. C **96**, 024627 (2017).

Examination of photon strength functions for ^{162,164}Dy from radiative capture of resonance neutrons. S. Valenta, B. Baramsai, T.A. Bredeweg, A. Couture, A. Chyzh, M. Jandel, J. Kroll, M. Krticka, H.E. Mitchell, J.M. O'Donnell, G. Rusev, J.L. Ullmann, and C.L. Walker. Phys. Rev. C 96, 054315 (2017).

Correlated fission data measurements with DANCE and NEUANCE. B. Baramsai, T.A. Bredeweg, A. Couture, A. Favalli, M. Jandel, A.C. Hayes, K.D.Ianakiev, M.L. Iliev, T. Kawano, S. Mosby, G. Rusev, I. Stetcu, P. Talou, J.L. Ullmann, D.J. Vieira, and C.L. Walker. Nucl. Instru, Methods A, **882**, 105 (2018).

Unifying measurement of ^{239}Pu(n,γ) in the keV to MeV energy regime. S. Mosby, T.A. Bredeweg, A. Couture, M. Jandel, T. Kawano, J.L. Ullmann, R.A. Henderson, and C..Y. Wu. Phys. Rev. C **97**, 041601(R) (2018).

Measurements of the Cu-65 (n,gamma) cross section using the Detector for Advanced Neutron Capture Experiments at LANL. C.J. Prokop, A. Couture, S. Jones, S. Mosby, G. Rusev, J. Ullmann, and M. Krticka, Phys. Rev. C **99**, 055809 (2019).

Measurement of the neutron capture cross section on argon. V. Fischer, L. Pagani, L. Pickard, A. Couture, S. Gardiner, C. Grant, J. He, T. Johnson, E. Pantic, C. Prokop, R. Svoboda, J. Ullmann, and J. Wang, Phys. Rev. D **99**, 103012 (2019).

Synergistic Activities

Currently Instrument Scientist for the DANCE detector which will be used in this proposal. Extensive experience in developing and running experiments for DANCE.

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers Collaborators and Co-editors:

J.B. Albert (Indiana University), B. Baramsai (Glenn Research Center), J. Blackmon (LSU), T.A. Bredeweg (LANL), J.A. Becker (retired), E.M. Bond (LANL), B. Bucher (LLNL), M.Q. Buckner (LLNL), A. Chyzh (unaff.), A. Couture (LANL), S.J. Daugherty (IU), D. Denis-Petit (CEA_DAM), M. Devlin (LANL), A. Favalli (LANL), S. Fiebiger (Goethe University Frankfurt), V. Fischer (U. Cal. Davis), C. Grant (Boston University), A.C. Hayes (LANL), R.A. Henderson (LLNL), K.D. Ianakiev (LANL), M.L. Iliev (LANL), M. Jandel (U. Mass Lowell), T.N. Johnson (U Cal Davis), S. Jones (LANL), L.J. Kaufman (SLAC), T. Kawano (LANL), A.L. Keksis (LANL), K. Kelly (LANL), P.E. Koehler (LANL), M. Krticka (Charles University Prague), R.C. Haight (LANL, ret), K. Macon (Notre Dame), V. Meot (CEA-DAM), G.E. Mitchell (N.C. State Univ, ret.), B. Morillon (CEA-DAM), S. Mosby (LANL), M.Mumpower (LANL), T. O'Conner (IU), J.M. O'Donnell (LANL), L. Pagani (U. Cal. Davis), L.J. Pickard (U. Cal. Davis), C. Prokop (LANL), R. Reifarth (Goethe University Frankfurt), O. Roig (CEA_DAM), A.R. Roman (LANL), P. Romain (CEA-DAM), R.S. Rundberg (LANL), G. Rusev (LANL), T.M. Sprouse (LANL), I. Stetcu (LANL), R. Svoboda (U. Cal Davis), P. Talou (LANL), S. Valenta (Charles Univ), D.J. Vieira (LANL, ret.), C.L. Walker (LANL), C. Wolf (Goethe University Frankfurt), J.B. Wilhelmy (LANL, ret.), C.Y. Wu (LLNL)

Graduate and Postdoctoral Advisors and Advisees

Graduate Advisors:

Dr. Rochus Vogt (Cal Tech) (retired)

Dr. F. Paul Brady (Univ. California, Davis) (retired)

Postdoctoral sponsor:

Dr. R. J. Peterson (Univ. of Colorado, Boulder) (retired)

Aaron Couture		R&D Scientist 4	
INSTITUTION AND LOCATION	DEGREE	YEAR(s)	FIELD OF STUDY
University of Notre Dame	B. S.	1998	Physics & Math
University of Notre Dame	M. S.	2005	Nuclear Physics
University of Notre Dame	Ph. D.	2006	Nuclear Physics
Los Alamos National Laboratory	Post Doctoral	2006-2008	Nuclear Physics

PROFESSIONAL EXPERIENCE

August 2016 to Present	R&D Scientist 4	LANL/P-27
February 2015 to Present	Team Leader, Nucl. Astro. and Structure	LANL/P-27
October 2014 to August 2016	R&D Scientist 4	LANL/P-27
March 2010 to October 2014	R&D Scientist 3	LANL/LANSCE-NS
July 2008 to March 2010	R&D Scientist 2	LANL/LANSCE-NS
May 2008 to July 2008	Technical Staff Member	LANL/LANSCE-NS

PUBLICATIONS (out of 98)

- "Direct measurements of neutron capture on radioactive isotopes", A. Couture and R. Reifarth, *At. Data and Nucl. Data Tables* 93 (2007) 807-830.
- "New Precision Measurements of the ^{235}U(n,γ) Cross Section" M. Jandel, T. A. Bredeweg, E. M. Bond, M. B. Chadwick, A. Couture, J. M. ODonnell, M. Fowler, R. C. Haight, T. Kawano, R. Reifarth, R. S. Rundberg, J. L. Ullmann, D. J. Vieira, J. M. Wouters, J. B. Wilhelmy, C. Y.Wu, and J. A. Becker. *Phys. Rev. Lett.* 109 (2012) 202506.
- "Cross sections from proton irradiation of thorium at 800 MeV" J. W. Engle, S. G. Mashnik, J. W. Weidner, L. E. Wolfsberg, M. E. Fassbender, K. Jackman, A. Couture, L. J. Bitteker, J. L. Ullmann, M. S. Gulley, C. Pillai, K. D.John, E. R. Birnbaum, and F. M. Nortier *Phys. Rev. C* **88** (2013) 014604.
- "Improved neutron capture cross section of ^{239}Pu" S. Mosby, T. A. Bredeweg, A. Chyzh, A. Couture, R. Henderson, M. Jandel, E. Kwan, J. M. O'Donnell, J. Ullmann, and C. Y. Wu, *Phys.Rev. C* **89** (2014) 034610.
- "Extended tests of an SU(3) partial dynamical symmetry" A. Couture, R. F. Casten, and R. B. Cakirli, *Phys. Rev. C* **91** (2015) 014312.
- "Neutron-induced fission cross section of ^{237}Np in the keV to MeV range at the CERN n TOF facility" M. Diakaki et al. (the n TOF Collaboration, CERN) *Phys. Rev. C* **93** (2016) 034614.
- "Experimental Neutron Capture Rate Constraint Far from Stability" S. N. Liddick, A. Spyrou, B. P. Crider, F. Naqvi, A. C. Larseon, M. Guttormsen, M. Mumpower, R. Surman, G. Perdikakis, D. L. Bleuel, A. Couture, L. Crespo Campo, A. C. Dombos, R, Lewis, S. Mosby, S. Nikas, C. J. Prokop, T Renstrom, B. Rubio, S. Siem, and S. J. Quinn *Phys. Rev. Lett.* **116** (2016) 242502.
- "Measurement of the ^{242m}Am neutron-induced reaction cross sections" M. Q. Buckner, C. Y. Wu, R. A. Henderson, B. Bucher, N. Wimer, A. Chyzh, T. A. Bredeweg, B. Baramsai, A. Couture, M. Jandel, S. Mosby, and J. L. Ullmann *Phys. Rev. C* **95** (2017) 024610.
- "Simple, empirical approach to predict neutron capture cross sections from nuclear masses" A. Couture, R. F. Casten, R. B. Cakirli *Phys. Rev. C Rapid Communication* **96** (2017) 061601R.
- "Unifying measurement of ^{239}Pu(n,γ) in the keV to MeV energy regime" S. Mosby, T. A. Bredeweg, A. Couture, M. Jandel, T. Kawano, J. L. Ullmann, R. A. Henderson, and C. Y. Wu *Phys Rev. C* Rapid Communication **97** (2018) 041601(R).

SYNERGISTIC ACTIVITIES

- Nuclear Astrophysics Town Meeting, Convener, Neutron Beams, s-Process, and NIF, College

Station, TX, August 2014.
- Perspectives in Nuclear Data for the Next Decade-2, International Organizing Committee, Bruyères-le-Chatel, France, October 2014.
- Capture Gamma Symposium, Program Committee, Shanghai, China, August 2017.
- Low Energy Community Meeting, Convener, Neutron, Gamma, and Plasma Experiments, Argonne, IL August 2017.

COLLABORATORS & CO-EDITORS: (last 48 months)
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Post Doctoral Sponsors: Dr. Robert C. Haight (Los Alamos National Laboratory) and Dr. Rene Reifarth (presently at University of Frankfurt, Germany, formally at Los Alamos National Laboratory).
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Undergraduate, University of Sofia, Nuclear Physics and Elementary Particles, MSc, 1999
Graduate, Technical University Dresden, Nuclear Physics, PhD, 2007
Postdoctoral training, Duke University, Nuclear Physics, 2007-2011
Postdoctoral training, Los Alamos National Lab, Nuclear Physics, 2011-2014

Research and Professional Experience:

2014-present	Staff Scientist, Los Alamos National Laboratory Neutron-induced fission and capture experiments at DANCE;
2011-2014	Postdoctoral research associate, Los Alamos National Laboratory Neutron-induced fission and capture experiments at DANCE; developing a portal monitor;
2011-2011	Research scientist, Duke University (γ,γ') and (γ,n) experiments at the HIγS facility; (n,n'x) experiment at TUNL's tandem lab
2007-2011	Postdoctoral research associate, Duke University (γ,γ') and (γ,n) experiments at the HIγS facility; (n,n'x) experiment at TUNL's tandem lab
2001-2007	Research associate, Research Center Dresden-Rossendorf Nuclear structure experiments at EuroBall; (γ,γ') experiments

Publications:
1. C. J. Prokop, *et al*., *Measurement of the ^{65}Cu(n,γ) cross section using the Detector for Advanced Neutron Capture Experiments at LANL*, Phys. Rev. C 99, 055809 (2019).
2. J. R. Winkelbauer, *et al*., *Statistical neutron capture in the limit of low nuclear level density*, Phys. Rev. C 99, 024318 (2019).
3. P. Talou, *et al*., *Correlated prompt fission data in transport simulations*, Eur. Phys. J. A 54, 9 (2018).
4. M. Jandel, *et al*., *Correlated fission data measurements with DANCE and NEUANCE*, Nucl. Instrum. Methods A 882, 105 (2018).
5. G. Rusev, *et al*., *Measurements of Correlated Fission Data with DANCE and NEUANCE,* World Scientific, ISBN: 978-981-3229-41-9, page 521 (2017).
6. A. P. Tonchev, *et al*., *Energy Evolution of the Fission-Product Yields from Neutron-Induced Fission of ^{235}U, ^{238}U,and ^{239}Pu: An Unexpected Observation,* World Scientific, ISBN: 978-981-3229-41-9, page 381 (2017).
7. **G. Rusev**, B. Baramsai, E. M. Bond, and M. Jandel, *Fission-neutrons source with fast neutron-emission timing,* Nucl. Instrum. Methods A 817, 26 (2016).
8. E. M. Bond, W. A. Moody, C. Arnold, T. A. Bredeweg, M. Jandel, and G. Rusev, *Preparation of Thin Iridium Targets by Electrodeposition for Neutron Capture Cross Section Measurements*, Journal of Radioanalytical and Nuclear Chemistry 307, 1981 (2016).

9. **G. Rusev**, *et al*., *Fission-fragment detector for DANCE based on thin scintillating films,* Nucl. Instrum. Methods A 804, 207 (2015).
10. M. Jandel, *et al*., *Capture and fission with DANCE and NEUANCE*, Eur. Phys. J A 51, 179 (2015).

Patents:

1. M. Jandel, G. Rusev, T. N. Taddeucci, "System for Detecting Special Nuclear Materials", U.S. Patent 9081108, filed March 4, 2013, issued July 14, 2015, assignee Los Alamos National Security, LLC

Synergistic Activities:

- Assistant Instrument Scientist for the DANCE detector
- Referee for Physical Review and Nuclear Instruments and Methods
- Member of the American Physical Society

Conferences/Workshop Organized/Co-Organized in the Last Five Years:

- Co-organizer of FIESTA School and Workshop on Nuclear Fission, Santa Fe, NM, USA, Sep. 2017

Awards:

- "*Forschungszentrum Dresden-Rossendorf Anerkennungspreis*" (Research Center Dresden-Rossendorf Recognition award) (2008). Awarded by the Research Center Dresden-Rossendorf.
- "*On the Spot Award*" (2012). Awarded by the Chemistry Division at the Los Alamos National Laboratory.

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Education and Training

1988 – 1991	Interdisciplinary Graduate School of Engineering Sciences, Kyushu University (Fukuoka, Japan) Department of Energy Conversion Engineering, Ph.D.
1986 – 1988	Graduate School of Engineering, Kyushu University, Department of Nuclear Engineering, MS
1982 – 1986	Faculty of Engineering, Kyushu University, Department of Nuclear Engineering, BS

Research and Professional Experience

2003 – the present	Theoretical Division, Nuclear Physics, Los Alamos National Laboratory
1991 – 2003	Interdisciplinary Graduate School of Engineering Sciences Kyushu University, Research Associate
(2017)	Guest Professor at Tokyo Institute of Technology, Japan
(1995 – 1996)	Guest Scientist at Forschungszentrum Karlsruhe, Germany

Selected 10 Related Publications in Last 5 Years

(1) "Transmission coefficients in compound-nucleus reaction theory," Y. Alhassid, G.F. Bertsch, P. Fanto, T. Kawano, Phys. Rev. C **99**, 024621 (2019).

(2) "Angular momentum of fission fragments," G.F. Bertsch, T. Kawano, L.M. Robledo, Phys. Rev. C **99**, 034603 (2019).

(3) "^{235}U(n,f) Independent Fission Product Yield and Isomeric Ratio Calculated with the Statistical Hauser-Feshbach Theory," Shin Okumura and Toshihiko Kawano and Satoshi Chiba and Patrick Talou and Patrick Jaffke, J. Nucl. Sci. Technol. **55**, 1009 (2018).

(4) "Estimation of M1 scissors mode strength for deformed nuclei in the medium- to heavy-mass region by statistical Hauser-Feshbach model calculations," M. R. Mumpower, T. Kawano, J. L. Ullmann, M. Krtička, T. M. Sprouse, Phys. Rev. C **96**, 024612 (2017).

(5) "Advances in nuclear reaction calculations by incorporating information from nuclear mean-field theories," Toshihiko Kawano, EPJ Web of Conferences, **146** 12004 (2017).

(6) "Constraining the calculation of ^{234,236,238}U(n,γ) cross sections with measurements of the γ-ray spectra at the DANCE facility," J. L. Ullmann, T. Kawano, B. Baramsai, T. A. Bredeweg, A. Couture, R. C. Haight, M. Jandel, J. M. O'Donnell, R. S. Rundberg, D. J. Vieira, B. Wilhelmy, M. Krtička, J. A. Becker, A. Chyzh, C. Y. Wu, G. E. Mitchell, Phys. Rev. C **96**, 024627 (2017).

(7) "Neutron-γ competition for β-delayed neutron emission," M. R. Mumpower, T. Kawano, P. Möller, Phys. Rev. C **94**, 064317 (2016).

(8) "Statistical Hauser-Feshbach theory with width-fluctuation correction including direct reaction channels for neutron-induced reactions at low energies," T. Kawano, R. Capote, S. Hilaire, P. Chau Huu-Tai, Phys. Rev. C **94**, 014612 (2016).

(9) "Random-matrix approach to the statistical compound nuclear reaction at low energies using the Monte Carlo technique," T. Kawano, P. Talou, H. A. Weidenmüller, Phys. Rev. C **92**, 044617 (2015).

(10) "Statistical and evaporation models for the neutron emission energy spectrum in the center-of-mass system from fission fragments," T. Kawano, P. Talou, I. Stetcu, M.B. Chadwick, Nucl. Phys. A **913**, 51 (2013).

Synergistic Activities

- Chair, Nuclear Reaction Working Group, U.S. Nuclear Data Program
- Member of IAEA international collaboration on Photon Strength Function and Photonuclear Data Library, and Reference Input Parameter Library
- Organize international conferences, and serve international advisory and program comittee members of major nuclear data related conferences. The conferences in these 3 years includes:
  - Co-organizer: Workshop on Elastic/Inelastic Scattering, WINS2016, Santa Fe, USA, April 2016
  - International Program Committee: Int. Nuclear Data for Science and Technology, Bruge, Belgium, Sept. 2016
  - Organizer: Int. Conf. Nuclear Reaction Mechanisms, Varenna, Italy, June 2018
  - International Advisory Committee: Int. Compound Nuclear Reaction and Related Topics, Berkeley, USA, Sept. 2018
  - International Program Committee: Int. Nuclear Data for Science and Technology, Beijing, China, May 2019

Identification of Potential Conflicts of Interest

Collaborators: L. Bernstein (UCB), G. Bertsch (UW), D.A. Brown (BNL) R. Capote (IAEA), M.B. Chadwick (LANL), P. Chau Huu-Tai (CEA/DAM), S. Chiba (Tokyo Tech), A. Couture (LANL), M. Devlin (LANL), M. Dupuis (CEA/DAM), N. Fotiades (LANL), M. Herman (BNL), S. Hilaire (CEA/DAM), O. Iwamoto (JAEA), P. Jaffke (LANL), M. Jandel (U. Mass Lowell), M. Krtička (Charles U., Prague), S. Kunieda (JAEA), P. Moller (LANL), S. Mosby (LANL), M.R. Mumpower (LANL), R.O. Nelson (LANL), D. Neudecker (LANL), S. Okumura (IAEA) P. Roman (CEA/DAM), P. Talou (LANL), J. Randrup (LBNL), G. Rusev (LANL), T. M. Sprouse (U. ND), I. Stetcu (LANL), A. P. Tonchev (LLNL), J.L. Ullmann (LANL), R. Vogt (LLNL), H.A. Weidenmüller (MPI) M.C. White (LANL)
PostDoc: M. Verriere (LANL)

Appendix 2: Current and Pending Support

John Ullmann

Current Support
Source of Support: Los Alamos National Laboratory / NNSA Defense Programs
Project/Proposal Title: (Several)
Total Award period: Ongoing
Person-Months per year committed to project: 12

Pending Support:
(This proposal)
Source of Support: DOE LAB-19-2114
Proposal Title: Precision Determination of the ^{235}U neutron-capture cross section
Total Award Amount: $432K
Total Award Period Covered: 10/1/2020 – 9/30/2022
Person-months per year committed to project: 5 (FY2020)
Person-months per year committed to project: 2 (FY2021)

Aaron Couture

Current Support
Source of Support: Los Alamos National Laboratory / NNSA Defense Programs
Project/Proposal Title: (Several)
Total Award period: Ongoing
Person-Months per year committed to project: 12

Pending Support:
(This proposal)
Source of Support: DOE LAB-19-2114
Proposal Title: Precision Determination of the ^{235}U neutron-capture cross section
Total Award Amount: $432K
Total Award Period Covered: 10/1/2020 – 9/30/2022
Person-months per year committed to project: 1 (FY2020)
Person-months per year committed to project: 1 (FY2021)

Toshihiko Kawano

Current Support
DOE/SC
U.S. Nuclear Data Program
320K
30%
continuous
Develop new nuclear reaction and structure theories,
and provide evaluated nuclear data files to ENDF library.

DOE/NNSA NA22
Fission In R-process Elements (FIRE)
160K
10%
FY2017 - FY2022
Develop a fission model in the fission-cycle in the r-process nucleosynthesis.
Mentor a postdoc and collaborate with scientists at U. Notre Dame, and NCSU.

DOE/NNSA NA22
Energy-dependent fission product yield evaluation
700K
60%
FY2019 - FY2024
Produce a new evaluated fission product yield data library

Pending Support:
(This proposal)
Source of Support: DOE LAB-19-2114
Proposal Title: Precision Determination of the ^{235}U neutron-capture cross section
Total Award Amount: $432K
Total Award Period Covered: 10/1/2020 – 9/30/2022
Person-months per year committed to project: 1 (FY2020)
Person-months per year committed to project: 1 (FY2021)

Gencho Rusev

Current Support

Source of Support: NNSA Defense programs
Project/Proposal Title: DANCE Experiments
Total Award Amount: $300k
Total Award Period Covered: Ongoing
Person-Months Per Year Committed to the Project: 3

Source of Support: NNSA Defense programs
Project/Proposal Title: Nuclear Data Measurements
Total Award Amount: $240k
Total Award Period Covered: Ongoing
Person-Months Per Year Committed to the Project: 3

Source of Support: NNSA Defense programs
Project/Proposal Title: Subcritical Experiments
Total Award Amount: $160k
Total Award Period Covered: Ongoing
Person-Months Per Year Committed to the Project: 3

Source of Support: NNSA DNN R&D
Project/Proposal Title: Next Generation Correlated Fission Measurements
Total Award Amount: $150k
Total Award Period Covered: Through FY19
Person-Months Per Year Committed to the Project: 3

Pending Support:
(This proposal)
Source of Support: DOE LAB-19-2114
Proposal Title: Precision Determination of the ^{235}U neutron-capture cross section
Total Award Amount: $432K
Total Award Period Covered: 10/1/2020 – 9/30/2022
Person-months per year committed to project: 1.8 (FY2020)
Person-months per year committed to project: 1.8 (FY2021)

Source of Support: DOE Office of Nuclear Energy
Award or other Identifying Number: current proposal
Project/Proposal Title: Determining P(nu) from a Egtot vs. TKE correlated measurement with DANCE
Total Award Amount:
Total Award Period Covered: 3 years
Person-Months Per Year Committed to the Project: 1.8

Source of support: LANL / LDRD

Project/proposal title: Predictive Understanding of Device Performance through Innovative Measurement, Modeling, and Simulation on Radiochemical Dosimeters
Total award amount: proposal under review
Total award period covered: 3 years
Person-months per year committed to the project: 3.6

Appendix 3: Bibliography and References

1. "The CIELO Collaboration: Neutron Reactions on ^{1}H, ^{16}O, ^{56}Fe, ^{235,236}U, and ^{239}Pu" M.B. Chadwick, et al., Nuclear Data Sheets 118, 1 (2014).

2. OECD/NEA High-Priority Data List: http://www.oecd-nea.org/dbdata/hprl.

3. https://www.nndc.bnl.gov/exfor

4. "IAEA CIELO Evaluation of Neutron-induced Reactions on ^{235}U and ^{238}U Targets" R. Capote, et al., Nuclear Data Sheets **148**, 254 (2018).

5. "New Precision Measurements of the ^{235}U(n,γ) Cross Section" M. Jandel, et al., Phys. Rev. Lett. **109**, 202506 (2012).

6. "Novel method to study neutron capture of ^{235}U and ^{238}U simultaneously at keV energies" A. Wallner, et al., Phys. Rev. Lett. **112**, 192501 (2014).

7. "Progress in analysis of ^{235}U(n,gamma) data measured at the DANCE + NEUANCE facility" G. Rusev, Los Alamos Report LA-UR-18-29381, 2018 (Unpublished).

8. "Cross section and γ-ray spectra for ^{238}U(n,γ) measured with the DANCE detector array at the Los Alamos Neutron Science Center." J.L. Ullmann, et al, Phys. Rev. C **89**, 034603 (2014).

9. "Correlated fission data measurement with DANCE and NEUANCE" M. Jandel, et al., Nucl. Instr. And Methods in Physics Research A **882**, 105 (2018).

10. "Evaluation of the Neutron Data Standards" A.D. Carlson, et al., Nuclear Data Sheets **148**, 143 (2018).

11. "Constraining the calculation of ^{234,236,238}U(n,γ) cross sections with measurements of the γ-ray spectra at the DANCE facility." J. L. Ullmann, et al., Phys. Rev. C **96,** 024627 (2017).

Appendix 4: Facilities and Other Resources

This project will be based in the office space of P-27 at LANSCE. It will employ the set of computers and data-storage RAID's acquired by the DANCE collaboration at LANSCE.

Appendix 5: Equipment

No equipment, other than the computers mentioned in Appendix 4, will be needed.

Appendix 6: Data Management Plan

The raw data that will be analyzed are stored on local LANL analysis servers, and secondary backups of the raw data have been made to 2 sets of offline hard drives, which are stored in different physical locations. The raw data were obtained by a previous LANSCE experiment.

The analysis and simulation software necessary for the analysis of the DANCE data is maintained on a redundant storage system, with daily backups through LANL's institutional rescue storage system. The DANCE Data Acquisition and Analysis package has recently been approved for release as open source software through GitHub on a GPLv2 license. It is anticipated that the full analysis software package will be available by January, 2020.

Cross sections and other results of the analysis will be published in the open literature and presented in national and international conferences. Tables of final cross sections will be deposited with the National Nuclear Data Center.